



New Light on How Metals Change Shape at the Nanoscale

New Deformation Mechanism Discovered

A team of researchers at the University of Pittsburgh, working with the staff and facilities of LBNL's National Center for Electron Microscopy (NCEM), have made a fundamental discovery concerning the mechanism by which nanocrystalline metals respond to mechanical deformation. Their work shows that as nanosized metal grains become smaller, a new deformation mode involving "grain boundary mediated processes" replaces "nucleation and motion of lattice dislocations" as the dominant mechanism of the deformation.

Ordinary coarse-grained metals such as nickel deform in response to mechanical stress when parts of a grain slip past one another as dislocations—local areas of extra planes of atoms in the grain—move through them. The process has been compared to moving a rug by flapping one end of it to create a wave, causing the rug to inch along bit by bit. However, this mechanism cannot operate if the rug is too short. Likewise, if the dimensions of the crystal grains are too small, dislocations cannot be created and cannot glide through the grain to allow deformation. Theorists have proposed that when grain sizes are too small for dislocations, a different mode of deformation comes into play: the grain boundaries themselves move, sliding past one another and then rotating to find new ways of fitting together. However, previous *ex-situ* work had been inconclusive regarding which mechanism is active during deformation at the nanoscale.

In order to catch deformation "in the act" NCEM's *In-Situ* Microscope was used to perform detailed electron microscopy while a nanocrystalline film was being stressed. High quality samples of nickel prepared at DOE's Sandia National Laboratories were used in this fundamental study. Nanocrystalline samples were mounted in a probe that placed them under tensile load while images of small regions of the sample were captured on videotape at a rate of 30 frames per second. Detailed observation of images obtained under so-called "dark field" conditions revealed small regions rapidly brightening and growing larger. This is the signature of grain rotation and sliding and provides direct confirmation of the grains sliding and rotating via a grain boundary mechanism. Study of many individual images revealed that the transition from the dislocation motion to grain-boundary deformation mechanism, which begins to appear as the grain size is reduced below 20 nm, is continuous rather than sharp. In fact, trapped dislocations (evidence that the bulk mechanism is still partially operational) in the crystal lattice were observed even when the average grain size was as small as 10 nanometers.

It is known that as the grain size of a metal shrinks, it can become many times stronger. It also, however, usually loses ductility. The results here reveal the mechanism behind this mechanical change and, in this context, should help guide the design of optimum metals and alloys.

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Zhiwei Shan, E. A. Stach, J. M. K. Wiezorek, J. A. Knapp, D. M. Follstaedt, and S. X. Mao, "Grain boundary-mediated plasticity in nanocrystalline nickel," *Science*, 30 July 2004.